

GENERAL ENVIRONMENTAL VERIFICATION SPECIFICATION

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Abstract

The NASA Goddard Space Flight Center's General Environmental Verification Specification (GEVS) for STS and ELV Payloads, Subsystems, and Components is currently being revised based on lessons learned from GSFC engineering and flight assurance. The GEVS has been used by Goddard flight projects for the past 17 years as a baseline from which to tailor their environmental test programs. A summary of the requirements and updates are presented along with the rationale behind the changes. The major test areas covered by the GEVS include mechanical, thermal, and EMC, as well as more general requirements for planning, tracking of the verification programs.

Keywords

Test, Loads, Mechanical, Thermal, Vibroacoustics, Shock

The General Environmental Verification Specification (GEVS) provides the baseline environmental test program for missions or flight hardware being developed or managed by the Goddard Space Flight Center (GSFC). The major test areas covered by the GEVS include mechanical, thermal, and EMC, as well as more general requirements for planning and tracking of the verification programs. The GEVS is currently being revised based on lessons learned from GSFC engineering and flight assurance.

Background

GSFC was established in January of 1959 and has a long history of developing environmental test requirements for space flight hardware. Throughout most of the 1960's, test requirements were created for each launch vehicle and provided specific tests and test levels. In 1969 the first "General" Environmental Test Specification was published covering several expendable launch vehicles (ELV's). The Goddard "General" specifications include:

- **S-320-G-1** General Environmental Test Specification for Spacecraft and Components. (1969),
- **GETS** General Environmental Test Specification. (ELV Payloads, last revision in 1978),
- **GEVS** General Environmental Verification Specification for STS Payloads, Subsystems and Components (1984),
- **GEVS-SE** General Environmental Verification Specification for STS & ELV Payloads, Subsystems and Components (1990),
- **GEVS-SE Rev A** General Environmental Verification Specification for STS & ELV Payloads, Subsystems and Components (1996).

The earlier requirements were more prescriptive providing specific tests and test levels depending on the launch vehicle. The 1984 GEVS became more tailorable, but was only for the Space Transportation System (STS). GEVS-SE provides a baseline for a low risk mission and some tailoring is expected to match the spacecraft configuration, launch vehicle, mission and level of risk accepted by the project.

The verification philosophy for Goddard has always been to “test as you fly”, or to test at the all-up level of assembly. However, it is also recognized that it is not possible to subject all the hardware elements to stresses more severe than expected at the all-up level. Test conditions can be better controlled and the hardware subjected to desired levels best at the lowest practicable level of assembly. Therefore Goddard verification requirements have generally been written assuming a modular, low-risk spacecraft that can be tested at various levels of assembly (component/unit, subsystem, and system). Testing is often performed at lower levels (assembly and sub-assembly) or at other intermediate levels in order to best qualify the hardware.

The levels of assembly designated in GEVS are basically the same as used by other organizations even though the names used may vary. The GEVS designations are given in Table 1.

Table 1
GEVS Level of Assembly

Level of Assembly	Examples
System Segment (Satellite, Payload, Spacecraft, Laboratory, Observatory, Space Vehicle, etc.)	Spacecraft Bus + Science Payload Launch Vehicle, IUS
Module	Spacecraft Bus, Science Payload, Payload Fairing
Subsystem	Instrument/Experiment, Structure, Attitude Control, C&DH, Thermal Control, Electrical Power, TT&C, Propulsion
Section (group of units/components not a subsystem)	Electronic Tray or Palette, Stacked units, Electronic Boxes Mounted on a Panel, Solar Array Sections
Unit or Component	Electronic Box, Gyro Package, Motor, Actuator, Battery, Receiver, Transmitter, Antenna, Solar Panel, Valve Regulator
Assembly	Power Amplifier, Regulator
Subassembly	Wire Harness, Loaded Printed Circuit Board
Part	Resistor, Capacitor, IC, Switch, Connector, Bolt, Screw, Gasket, Bracket, Valve Stem

The Systems Management Office (SMO) which is part of the Goddard Office of Systems Safety and Mission Assurance (OSSMA) is responsible for setting verification policy and publishing the GEVS. The requirements are currently being evaluated and recommendations for changes are being gathered. The revision process is worked very closely with the Applied Engineering and Technology Directorate (AETD). Recommended changes from both engineering and quality assurance are discussed with discipline experts at Goddard, and in some cases sent to the greater aerospace community for evaluation, and consensus agreement. Proposed changes reflect new technologies and techniques, clarifications of requirements as well as areas of concern where problems have been occurring or have high potential impact on mission success.

The new GEVS revision will not substantially change the Goddard verification or test philosophy, but will clarify some practices and bring more emphasis to the verification of various materials and mechanisms. The information provided here reflects the latest thinking on what should be in the GEVS, but is not necessarily the final version. Once the changes are agreed upon by engineering and quality assurance, the document will be subjected to a Center wide review and further revisions are possible.

A major change for the GEVS is to add "design" factors of safety for static loads, sine vibration and vibroacoustics. The increased use of composites and bonded joints has necessitated the inclusion of these design factors. Table 2 shows the Factor of Safety (FS) for various elements.

Table 2
Flight Hardware Design & Test Factors of Safety

Element	Static Load	Sine	Random/Acoustics
Limit	1.00	1.00	0 dB (1.00 rms)
Design FS			
Metallic Yield	1.25	1.25	1.6 rms
Metallic Ultimate	1.40	1.40	1.8 rms
Stability	1.40	1.40	1.8 rms
Beryllium Yield	1.40	1.40	1.8 rms
Beryllium Ultimate	1.60	1.60	2.0 rms
Composite Ultimate	1.50	1.50	1.9 rms
Bonded HC Inserts	1.50	1.50	1.9 rms
Test			
Acceptance Test	1.00	1.00	0 dB
Protoflight Test	1.25	1.25	+3 dB
Qualification Test	1.25	1.25	+ 3 dB

Loads

The GEVS has required extra margins for composites, beryllium, etc., but this revision clarifies the margins.

For strength qualification, loads testing must be shown to produce forces 1.25 times the limit at all structural interfaces and in structural elements that have been shown to have the lowest margins for all identified failure modes. As many test conditions as necessary shall be applied in order to achieve this requirement. Therefore, this qualification testing should be performed at the lowest practicable level of assembly to reduce over-testing and limit risk of damage at higher levels of assembly.

For metallic structure, GSFC may approve verification by analysis depending on model correlation, understanding of load path and previous history. However for stability, beryllium, composites, and bonded joints proof testing to protoflight levels is required.

For non-metallic structure all elements should be proof tested to 1.25 times the limit load. If this is not possible, proof testing a representative set of elements may be allowed. Minimum B-basis allowables based on coupon testing shall be used to qualify the structure. The project shall have a Process Control Plan and Damage Control Plan.

Similarly for bonded joints, if it is not feasible to test every joint a representative sample may be tested to qualification levels. Again minimum B-basis allowables from coupon testing shall be utilized.

Vibroacoustic Testing

Generally GEVS requires 3-axis random vibration testing at the component and subsystem/instrument levels of assembly. For smaller spacecraft, random vibration is also performed at the system level. An acoustic test is performed at the system level and at lower levels if the hardware is deemed susceptible. The GEVS revision will allow free-field conditions for acoustic testing. This change is due to the advances being made in the use of speakers for acoustic testing. As before the minimum test level is 138 dB. For cases where the maximum expected flight level is less than 138 dB, the spectral shape is maintained and the level increased to obtain the 138 dB test.

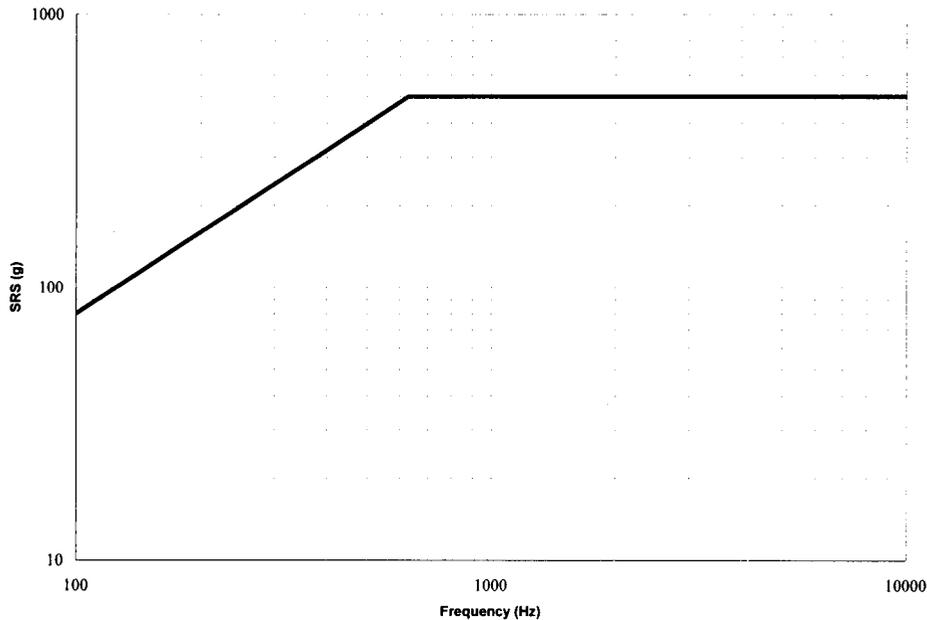
There is basically no change in the random vibration test requirements, but a clarification is made to allow notching below minimum workmanship levels when it is known that the minimum workmanship levels exceed design safety factors or can cause unrealistic modes of failure. Flight or test responses at higher levels of assembly and/or appropriate force limits must be known in order to utilize notching.

Shock

Testing is required for self-induced shocks. While most projects have deferred testing for externally generated shock environments to higher levels of assembly, a recommendation

is being made that they evaluate the hardware susceptibility and consider simulations at the unit level if the expected shock environment exceeds the levels given in Figure 1

Figure 1
Shock Response Spectrum
(Q=10)



Mechanical Function

Mechanical function tests and torque margin verification have been required. However, since mechanism operation is critical, considerable effort has been put into developing requirements for their design and verification.

- **Lubricants** - The selection of a lubricant for use in critical moving mechanical assemblies shall be based upon development tests of the lubricant that demonstrate its ability to provide adequate lubrication under all specified operating conditions over the design lifetime. Since life testing cannot typically provide proof of lubricant availability based on evaporation over the required life of the mechanism, an analysis shall be performed to show that there is an adequate amount of lubricant in the system (not including degradation) for the duration of the mechanism life with a margin greater than 10. Lubricant availability analyses based on degradation rates should be proven through life testing.
- **Ball bearings** - The design of each ball bearing installation shall be substantiated by analysis and either development tests or previous usage. The materials, stresses, stiffness, fatigue life, preload, and possible binding under normal, as well as the most severe combined loading conditions, and other expected

environmental conditions shall be considered. Alignments, fits, tolerances, thermal and load induced distortions, and other conditions shall be considered in determining preload variations. Bearing fatigue life calculations shall be based on a survival probability of 99.95 percent when subjected to maximum time varying loads. For non-critical applications or deployables, if nonquiet running is acceptable, and the bearing material is 52100 Carbon Steel or 440C Stainless Steel, the mean Hertzian contact stress shall not exceed 2760 megapascals (400,000 psi) when subjected to the yield load. During operation, the mean Hertzian contact stress shall not exceed 2310 megapascals (335,000 psi). For materials other than these, a Hertzian contact stress allowable shall be determined based on manufacturer recommendations with appropriate reduction factors for aerospace applications.

In addition to the requirements stated above, bearing applications requiring quiet operation or low torque ripple shall be designed so that the bearing race and ball stress levels are below the levels that would cause unacceptable permanent deformation during application of ascent loads. Where bearing deformation is required to carry a portion or all of the vehicle ascent loads, and where smoothness of operation is required on orbit, the mean Hertzian stress levels of the bearing steel (52100 and 440C) shall not exceed 2310 megapascals (335,000 psi) when subjected to the yield load. The upper and lower extremes of the contact ellipses shall be contained by the raceways. The stress and shoulder height requirements of the races shall be analyzed for both nominal and off-nominal bearing tolerances. During operation, the mean Hertzian contact stress should not exceed 830 megapascals (120,000 psi) over the worst case environment. For materials other than 52100 carbon steel and 440C stainless steel, a Hertzian contact stress allowable shall be determined based on manufacturer recommendations with appropriate reduction factors for aerospace applications.

- **Motors** - For applications where motor performance is critical to mission success, the design shall be based on a complete motor characterization at the minimum and maximum voltages from the spacecraft bus and motor driver and shall include as a minimum: rotor inertia, friction and damping parameters, back-EMF constant or torque constant, time constant, torque characteristics, speed versus torque curves, thermal dissipation, temperature effects, and where applicable, analysis to demonstrate adequate margin against back driving.
- **Run-in-test** - After initial functional testing, a run-in test shall be performed on each moving mechanical assembly before it is subjected to further acceptance testing, unless it can be shown that this procedure would be detrimental to performance and would result in reduced reliability. The primary purpose of the run-in test is to detect material and workmanship defects that occur early in the component life. Another purpose is to wear-in parts of the moving mechanical assembly so that they perform in a consistent and controlled manner. Satisfactory wear-in may be manifested by a reduction in running friction to a consistent low

level. The run-in test shall be conducted for a minimum of 50 hours except for items where the number of cycles of operation, rather than hours of operation, is a more appropriate measure of the capability to perform in a consistent and controlled manner. For these units, the run-in test shall be for at least 15 cycles or 5% of the total expected life cycles, whichever is greater. The run-in test conditions should be representative of the operational loads, speed, and environment; however, operation of the assembly at ambient conditions may be conducted if the test objectives can be met and the ambient environment will not degrade reliability or cause unacceptable changes to occur within the equipment such as generation of excessive debris. During the run-in test, sufficient periodic measurements shall be made to indicate what conditions may be changing with time and what wear rate characteristics exist. Test procedures, test time, and criteria for performance adequacy shall be in accordance with an approved test plan. All gear trains using solid or liquid lubricants shall, where practicable, be inspected and cleaned following the run-in test.

- **Torque or Force Margin** – The torque or force margin shall be determined by test to demonstrate the minimum requirements. Torque Margin (TM) is a measure of the degree to which the torque available to accomplish a mechanical function exceeds the torque required. The torque margin is simply the ratio of the driving or available torque to the required or resistive torques times appropriate Factor of Safety (FS) minus one. The torque margin requirement applies to all mechanical functions, those driven by motors as well as springs, etc. at beginning of life (BOL) only. End of life (EOL) mechanism performance is determined by life testing, and/or by analysis; however, all torque increases due to life test results should be included in the final TM calculation and verification. Positive margin must be shown for worst case conditions EOL predicted conditions and at the extreme operating parameters of the system (rate, acceleration, etc.).

Available torque (T_{avail}) and resistive torque (T_r) should, whenever possible, be determined by test under worst case conditions.

The Factor of Safety being used depends on the phase or time in the program according to the table 3.

Table 3
Torque Factors of Safety

Program Phase	Known Torque Factor of Safety (FS_k)	Variable Torque Factor of Safety (FS_v)
Preliminary Design Review	2.0	4.0
Critical Design Review	1.5	3.0
Acceptance / Qualification Test	1.5	2.0

The Torque Margin (TM) shall be greater than zero and shall be calculated using the following formula:

$$TM = \{T_{avail} / (FS_k \Sigma T_{known} + FS_v \Sigma T_{variable})\} - 1$$

Where:

Driving Torques:

T_{avail} = Minimum Available Torque generated by the mechanism at worst case environmental conditions at any time in its life. If motors are used in the system, T_{avail} shall be determined at the output of the motor, not including gear heads or gear trains at its output based on minimum supplied motor voltage. T_{avail} similarly applies to other actuators such as springs, pyrotechnics, solenoids, heat actuated devices, etc.

Resistive Torques:

ΣT_{known} = Sum of the fixed torques or forces that are known and quantifiable such as accelerated inertias ($T=I\alpha$) and not influenced by friction, temperature, life, etc. A constant Safety Factor is applied to the calculated torque.

$\Sigma T_{variable}$ = Sum of the torques or forces that may vary over environmental conditions and life such as static or dynamic friction, alignment effects, latching forces, wire harness loads, damper drag, variations in lubricant effectiveness, including degradation or depletion of lubricant over life, etc.

For linear devices, the term "force" shall replace "torque" in the above discussion.

Thermal

Goddard requires thermal-vacuum testing at component, subsystem, and system levels of assembly. Eight (8) thermal cycles are required on all hardware prior to assembly on the spacecraft. Normally four (4) cycles are performed at the component level and four (4) at the subsystem/instrument level. Four (4) cycles are also performed on the spacecraft making the total number of thermal cycles twelve (12). The major changes for thermal testing, other than clarifications, are to recommend a 5°C margin for acceptance testing and to increase the required margins and durations if tests are approved by Goddard to be performed at ambient pressure. Many Goddard projects already impose the 5°C margin for acceptance testing in vacuum. Recommendations are being made to increase test margins by an additional 15°C and to increase the number of cycles and dwell times by 50% if testing is performed at ambient pressure. Additional analysis will also be required.

EMC

The GEVS recommends testing of all hardware, but the EMC test program is tailored to the mission and it is recommended that all mission elements have a common EMC control plan that specifies the requirements for all hardware. The GEVS has been based

on MIL-STD-461C and projects may use later versions. At this time, no recommended changes have been made.

References

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